Stringent Tests of the *ab initio* Virial Equation of State for ^4He with Speed-of-Sound, Density and Burnett Data

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Theorists have calculated, *ab initio*, fully-quantum-mechanical 2nd and 3rd virial coefficients of helium and semi-classical 4th and 5th virial coefficients over wide temperature ranges. We test these theoretical results using previously-published, high-quality, measurements using three, very different techniques: (1) magnetic-suspension, dual-sinker densimetry (223 K < T < 500 K, p < 38 MPa), (2) resonator-based speed-of-sound measurements (98 K < T < 423 K, p < 15 MPa), and (3) pressure-ratio measurements from Burnett isothermal expansions (83 K < T < 323 K, p < 70 MPa). Within their scatter, most of the measurements above 225 K are consistent with the *ab initio* virial equation of state over the entire pressure range. The data from the densimeter and the acoustic resonator have small systematic offsets in the limit of zero pressure; we attribute these to plausible uncertainties in the concentration of impurities or uncertainties in the determinations of the pressure, the thermodynamic temperature or (in the case of the densimeter) the sinker's density. At 225 K and lower temperatures, the Burnett data and the speed-of-sound data systematically depart from the theoretical virial equation of state. The present comparisons of *ab initio* virial equations of state for helium to high-quality measurements illustrate the use of theoretical results to calibrate precision apparatus, thereby reducing the uncertainty of similar measurements made with other fluids. In temperature and pressure ranges where the theory and the thermodynamic measurements agree, the virial equation of state for helium can be used to critically test our understanding of critical venturis as flow standards.